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ABSTRACT

Three studies were conducted to investigate reasons for the difficulties that children under 5 years of age experience with class inclusion tasks. The studies tested the claim that such tasks have a structural complexity that is beyond the children's processing ability. In experiment 1, class inclusion tasks were compared with other classification tasks. A total of 27 children between 4 and 8 years of age participated. It was found that the inclusion relation per se was a source of difficulty independently of question asymmetry and the use of descriptors for the superordinate class. Experiment 2 used a new task that was isomorphic to inclusion, and that avoided the features that had led to misinterpretation of the inclusion task. Subjects were 18 children 3 or 4 years old and 18 children 5 or 6 years old. It was found that children under 5 continued to have difficulty because they were unable to integrate relations between subclasses and between the subclasses and the superordinate class. Experiment 3, which involved 90 children of 3-7 years, used the easy-to-hard paradigm for studying capacity limitations. It was found that children's class inclusion reasoning was capacity-limited. Results are interpreted as showing that structure-mapping theory can account for processing load effects in classification tasks. (RH)

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Processing Load Constraints: A Structure-Mapping Approach

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Abstract

Structure-mapping analysis can provide stable estimates of processing loads imposed by cognitive tasks. Analysis of hierarchical classification showed that it requires the system-mapping level of structure-mapping, which imposes a similar processing load to premise integration in transitive inference. This level is normally attainable at a median age of five years. In Experiment 1 class inclusion tasks were compared with other classification tasks and it was found that the inclusion relation per se is a source of difficulty, independently of question asymmetry and the use of descriptors for the superordinate class. In a second experiment a new task was used which is isomorphic to inclusion, and which avoids the features that have led to misinterpretation of the inclusion task. It was found that children under five years continued to have difficulty, because they were unable to integrate relations between subclasses, and between the subclasses and the superordinate class. In the third experiment the easy-to-hard paradigm for studying capacity limitations was used, and it was shown that children's class inclusion reasoning is capacity limited. The results are interpreted as showing that structure-mapping theory can account for processing load effects in classification tasks.

Processing Load Constraints: A Structure-Mapping Approach

The concept of class inclusion entails understanding the relations between a superordinate class and (at least) two subordinate classes; e.g. the relations between the class of fruit and the class of apples and the class of pears. The structure of the inclusion concept, together with an example, is shown in Figure 1.

Insert Figure(s) 1 about here

The classical Piagetian technique for assessing understanding of inclusion was to ask children to compare the superordinate class with one of the subordinate classes; for example, are there more fruit or more apples? This task has often proved difficult for children until about 6-7 years of age.

There is now an extensive literature on the problem (see Halford, 1982; Winer, 1980, for reviews). Several hypotheses have been advanced to explain the difficulty that children have with the task. These are summarized in Figure 2.

Insert Figure(s) 2 about here

Piaget (1950) contended that children could not understand inclusion until they acquired the appropriate grouping, when they reached the concrete operational stage of development. However the work of Osherson (1974) and others does not

support Piaget's psycho-logic, including the theory of groupings. In general models based on formal logic have not given successful accounts of human reasoning (Cheng and Holyoak, 1985; Johnson-Laird, 1983).

The second class of explanations proposed that children were led into error on the class inclusion task by their set quantification processes (Klahr & Wallace, 1976; Trabasso, Isen, Dolecki, McLanahan, Riley & Tucker, 1978; Wilkinson, 1976). The proposal is that children's rule that you do not count objects twice prevents them from counting the whole of the superordinate set. Suppose children are shown 10 apples and five bananas, and are asked whether there are more apples or more fruit. They count the apples, but when counting the fruit, they only count the bananas, because the apples have already been counted. Therefore there are more apples (10) than fruit (5).

This model does not explain how we can solve inclusion tasks without knowing how many items there are in each class. For example, we all know there are more children than girls, but no-one knows how many of each there are. We know it because of the inclusion logic; since girls are included in children, and there are children that are not girls (girls are a proper subset of children), it follows that there are more children than girls. The set quantification models do not capture this logic.

The third class of explanations is that children interpret the question as requiring subclass comparison, because the exclusive or distributive comparison is more common in language use than the inclusive comparison. Consistent with

this hypothesis it has been found that anything that helps make it clearer that a subclass-superordinate class comparison is intended improves performance. A label for the superordinate class, or a collective term such as "family", "pile", or "bunch" (more apples or more fruit in the whole pile?) helps the child to recognize that a subclass-superordinate class comparison is intended.

A related hypothesis is that children supply missing modifiers, and thereby interpret superordinate classes as subclasses (Grieve & Garton, 1981). For example, when children were shown four horses, three of which are black and one white, and asked whether there are more horses or more black horses, they interpreted the question to mean :more white horses or more black horses?" That is, they added the modifier white to the first class mentioned in the question, thereby interpreting it as a subclass rather than a superordinate class.

The final class of explanations is that the task is unfamiliar to young children, and they perform better if it is presented in a more compatible format (McGarrigle, Grieve & Hughes, 1978; Siegel, McCabe, Brand & Matthews, 1978). Using tasks that were more suitable for young children, these authors found improved performance, but in most experiments children only reached approximately 50 percent correct, which does not exceed the chance baseline. Exceptions occurred in experiments using four steps to a chair and two further steps to a table. Children were asked whether a teddy would have more steps to go to the chair or more steps to the table, and above chance performance was obtained from three-year olds on three out of eight occasions. Steps to the chair are included

in steps to the table, so at first sight this seems like a test of inclusion reasoning. It can however be answered by simply comparing two distances, and may not reflect inclusion reasoning at all.

In general, although some important factors affecting children's performance on class inclusion have been demonstrated, there is still doubt as to whether children under five years can perform the task. Furthermore an elegant analysis by Hodkin (1987) showed that much of the apparent improvement in performance of younger children was due to guessing, and that there was no evidence of class inclusion reasoning by children under five years of age.

Although factors that lead children to misinterpret the inclusion question are one source of difficulty, it is not clear that they provide the whole explanation. We therefore want to propose a further explanation. This is that the structural complexity that is inherent in class inclusion overloads the processing capacity of most children younger than about five years of age. A method of analysing structural complexity has been developed by Halford (1988a,b) based on structure mapping, a concept that has recently become prominent in the theory of analogies (Gentner, 1983), transfer of learning (Reed, 1987) and mental models (Holland, Holyoak, Nisbett & Thagard, 1986).

The source of difficulty in the inclusion task is in the information that is necessary to identify superordinate and subordinate classes. The problem is that no class is inherently a superordinate or subordinate. For example "fruit" is a superordinate of apples and bananas, but it is a subordinate of food (fruit and meat

are both food). The problem is that to identify a class as subordinate or superordinate, you need to consider its relations to at least two other classes.

In the example in Figure 1, we know that fruit is the superordinate because it has two subclasses, we know that apples is a subordinate because it is part of the class of fruit, and that there is (at least) one other subclass of fruit, bananas. Thus we can only identify superordinate classes and subclasses by looking at the structural relations between the classes. To qualify as a superordinate, a class must have at least two nonempty subclasses. To qualify as a subordinate, a class must be part of another class, and there must be at least one other class that is part of the same superordinate class.

This means that, in order to perform class inclusion reasoning, a person needs a schema or mental model that includes a superordinate and at least two subclasses, as shown in Figure 1. The schema expresses the idea that there is a superordinate class, which contains at least two subclasses. To solve a problem, the person must identify the superordinate and subclasses in the problem. This identification process is expressed in Figure 1 by mapping the problem classes into the schema classes, as shown by the vertical arrows.

This structure mapping diagram permits the structural complexity of the concept to be analyzed. We can only map the problem into the schema by considering two relations. We either have to consider two inclusion relations (e.g. that apples and bananas are both included in fruit), or we have to consider one inclusion and one complementarity relation (e.g. that apples are included in fruit,

and that apples are the complement of bananas).

A task in which two relations must be considered jointly to map the problem structure into the schema structure is a *system mapping*, as defined by Halford (1987a,b). That is, it has the same degree of structural complexity as transitive inference, systematicity in analogies, compensation rules on the balance scale, or the dimension checking strategy in Levine's (1966) blank trials task. Structure mapping theory assigns tasks to category of equal structural complexity.

Previous research has shown that system mapping tasks impose higher processing loads than tasks that require lower levels of mapping, based on single relations (relational mappings) or similarity of elements (element mappings) (Maybery, Bain & Halford, 1986). It has also been shown that system mapping tasks are difficult for children below five years of age, and that the reason is the processing loads they impose (Halford, Maybery & Bain, 1986).

Accordingly it is argued that one reason why children younger than five have difficulty with class inclusion tasks is that it has a structural complexity that is beyond their processing ability. The purpose of this paper will be to test that claim, and also to investigate some of the other reasons for the difficulties that young children have.

Experiment 1

27 Children aged 4-8 years were presented with three types of array, as shown in Figure 3. Array A consisted of an inclusion hierarchy with three levels, and both Arrays B and C had two levels. Each array was used three times,

with a different set of materials. The questions asked (e.g are there more horses or more small horses?) in respect of each array are shown in Figure 3. The inclusion questions were asked equally often with the major and minor subset (e.g. for the major subset, horses versus small horses; for the minor subset, horses versus large horses). There were therefore seven types of comparisons altogether.

Insert Figure(s) 3 about here

Array A was used so that both symmetric and asymmetric inclusion questions could be used. Arrays B and C were used to control for the possibility that the larger size of array A, relative to those used in most inclusion studies with small children, would affect the results.

Results

The results were analyzed by a series of planned comparisons. There was no effect of same level/different level noninclusion questions, so the data were collapsed over this factor. There was a significant effect of age, with the 4-year olds being poorer than the 6- and 8-year olds, which did not differ from each other, as shown in Table 1.

Insert Table(s) 1 about here

The noninclusion questions were answered better than both the asymmetric and symmetric inclusion questions, which did not differ from each other, as shown in Table 2.

Insert Table(s) 2 about here

There was a small but significant effect of array size, with the large array (array A) being performed worse than the small arrays (arrays B and C). The means were 4.09 and 3.83 respectively. This effect did not interact with any other factor.

There was an interaction of age x asymmetric-asymmetric inclusion question x major-minor subset, as shown in Figure 4, the 6- and 8-year olds only, the

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Insert Figure(s) 4 about here

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tendency to answer inclusion questions involving the minor subset better is more pronounced for the symmetric items. This suggests that the tendency to misinterpret the inclusion question as a subset comparison question is greater with

symmetric questions, contrary to Grieve & Garton (1981). It also appears that this factor has more influence on children over five years.

The results indicate that inclusion questions are more difficult than noninclusion questions of whatever kind, and that the effect is only partially explained by the hypothesis that children misinterpret the question. The hypothesis that inclusion questions are interpreted as requiring subset comparisons implies that items involving the minor subset would be answered better. This does occur, but appears more strongly with older children, who perform above chance on the inclusion question, than with 4-year olds who do not. Therefore this factor cannot account for the poor performance of the four-year olds.

The argument of Grieve and Garton (1981) that inclusion questions are difficult because their asymmetry induces children to add a modifier is not supported. Symmetric questions were not answered better than asymmetric questions. Grieve and Garton used only asymmetric inclusion questions (more horses or more white horses). When both symmetric and asymmetric inclusion questions are used, and are compared with noninclusion questions, it turns out to be the fact that a question calls for an inclusion comparison, not its asymmetry, that is associated with difficulty.

Nevertheless, the fact that the subset size effect occurs indicates there is potential for inclusion questions to be misinterpreted as requiring subset comparisons, even though this is not the sole cause of the difficulty children experience, and is not the major factor in the age effect. Therefore a test was

designed to avoid this problem.

The new test is an isomorph of the inclusion task. It is based on the idea of a minimal inclusion hierarchy, which consists of two objects each with two attributes, one shared and one distinct, as shown in Figure 5.

Insert Figure(s) 5 about here

The example shown consists of a red triangle and a red square. The shared attribute is "red", and the distinct attributes are "triangle" and "square". Thus triangle and square are included in red.

To avoid the semantic difficulties with the inclusion question, children were tested for recognition of an inclusion hierarchy in the context of a game. They were shown two dolls called Sally and John, and told that they liked to have toys that were a bit the same and a bit different. The child was asked to help the experimenter find a present that Sally and John would like. The children were then shown three kinds of pairs, as shown in Figure 5; inclusive (e.g., red square, red triangle); disjoint (e.g., red square, green triangle); identical (e.g., red square, red square). Very simple stimuli were used to facilitate encoding of the relevant relations.

Eighteen 3-4 year olds and 18 5-6 year olds were given four trials of each type, inclusive, disjoint, and identical. Feedback, pointing out shared or distinct attributes, was given on each trial.

The results are shown in Figure 6.

Insert Figure(s) 6 about here

There was a significant age x trial block interaction, reflecting improvement over trials for the 5-6 year olds only. Only the older group performed significantly above chance on any trial block.

Although this task is very simple, the 3-4 year olds did not learn to make the discrimination. They were not able to distinguish cases where stimuli had one shared and one distinct attribute. In Experiment 1, and in previous research, they also had difficulty with the class inclusion task, which is isomorphic to the discrimination task used in Experiment 2. This suggests that the structural complexity of these tasks might be the factor responsible. According to structure mapping theory, both the inclusion and discrimination tasks require system mappings, which impose processing loads that exceed the capacity of children below a median age of five years. Experiment 3 was designed to test this hypothesis directly.

Experiment 3

This experiment was based on the easy-to-hard paradigm (Hunt & Lansman, 1982) for assessing capacity limitations, shown in Figure 7.

Insert Figure(s) 7 about here

There is both an easy and a hard version of the classification task. The easy version is performed both alone, and jointly with a secondary task, probe reaction time. The logic of the paradigm is that, if performance on the hard classification task is limited by children's capacity, it should be predicted by probe reaction time when performed jointly with the easy classification task. The reasoning is that those children with higher processing capacity will have more capacity to spare when performing the easy classification task, and therefore will show better probe reaction performance. Therefore, if the hard classification task is capacity limited, performance on it should be predicted by probe reaction time performed jointly with the easy classification task. To remove variance due to factors other than capacity, performance on the easy classifiction task, and the probe reaction time task, when performed alone, is partialled out. This paradigm permits the hypothesis that a task is capacity limited to be tested, and it is not subject to the ambiguities of interpretation attributed by Navon (1984) to the dual-task interference paradigm.

The hard classification task was to identify inclusive sets, as in Experiment 2. The easy task required children to identify either two identical objects (red square, red square) or two disjoint objects (red square, green triangle). In structure mapping terms, both of the easy task require only a single relation to

be identified (same in one case, different in the other). Therefore they are relational mappings, which impose lower processing loads than system mappings.

Ninety children, aged 3-7 years were tested on this paradigm.

Results

The easy classification task and the secondary task, performed jointly, predicted performance on the inclusive classifiction task, with the separate predictors partialled out. In terms of the easy-to-hard paradigm, this pattern of results indicates that performance on the classification task was capacity limited.

As in Experiment 2, 3-4 year olds did not perform better than chance on the inclusive classification task, but were 82 percent correct on the identical and disjoint tasks. This shows that it was not the task format or demands that were responsible for their failure in either this experiment or in Experiment 3.

Discussion

In Experiment 1, 3-4 year olds did not perform better than chance on class inclusion, and this was not explained by the misinterpretation hypothesis, even though this factor did affect the performance of older children. Inclusion tasks were found to be more difficult than noninclusion, irrespective of the type of questions asked.

In Experiment 2 an isomorph of the class inclusion task was used to obviate ambiguities induced by the linguistic form of the class inclusion question. The 3-4 year olds still performed no better than chance. In Experiment 3 it was shown, using the easy-to-hard paradigm, that this result was due to capacity

limitations.

The pattern of results obtained in all three experiments is consistent with the hypothesis that 3-4 year olds fail class inclusion because the structural complexity of the concept imposes processing demands that are beyond their capacity. Class inclusion requires the superordinate and subordinate classes to be identified by their relations to each other. It has been shown in other contexts, such as transitivity, that concepts that are defined by a composition of relations, impose processing demands that are too great for most preschool children. Both class inclusion and transitivity require system mappings (Halford 1988a, 1988b), and that class of tasks has consistently been found to be difficult for children below a median age of five years, because of the processing demands they impose (Halford 1987a, 1987b, in preparation).

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Figure Captions

Figure 1. The class inclusion schema, mapped into an inclusion hierarchy.

Figure 2. Summary of hypotheses to explain the difficulty of class inclusion.

Figure 3. Arrays used in experiment 1, and questions asked.

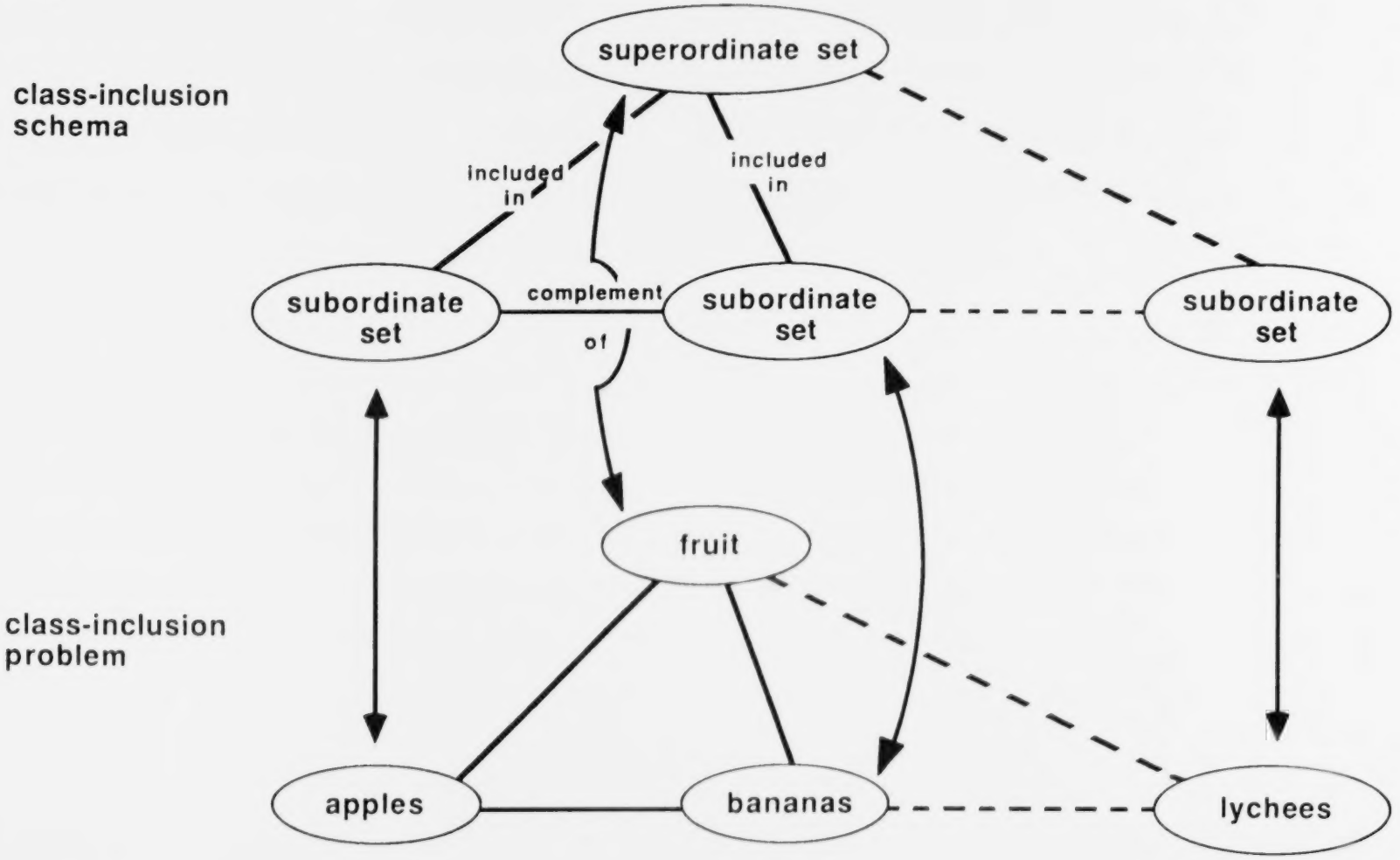
Figure 4. Age by comparison by subset size interaction in Experiment 1.

Figure 5. Inclusion isomorph task used in Experiments 2 and 3.

Figure 6. Age by trial blocks interaction in Experiment 2.

Figure 7. The easy-to-hard paradigm, as used in Experiment 3.

Fig. 1


class-inclusion schema
superordinate set
included in
included in
subordinate set
complement
of
subordinate set
subordinate set
class-inclusion problem
fruit
apples
bananas
lychees

Explanations for class-inclusion difficulty

1. Piagetian grouping hypothesis

2. Set quantification hypothesis:
   Klahr & Wallace, 1976
   Trabasso, Isen, Dolecki, McLanahan,
   Wilkinson (1976)

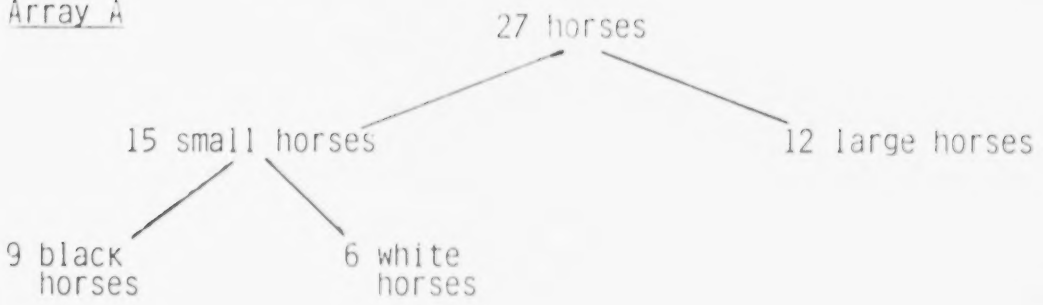
3.A Subset comparison hypothesis:
   e.g. Kalil, Youseff & Lerner, 1974
   Winer, 1974
   McGarrigle, Grieve & Hughes (1978)

3.B Related hypotheses:
   Class - collection hypothesis:
   Markman & Siebert (1976)

3.C Second-modifier hypothesis:
   Grieve & Garton (1981)

4. Task familiarity hypothesis:
   McGarrigle, Grieve & Hughes (1978)
   Siegel, McCabe, Brand & Matthews (1978)

Array A

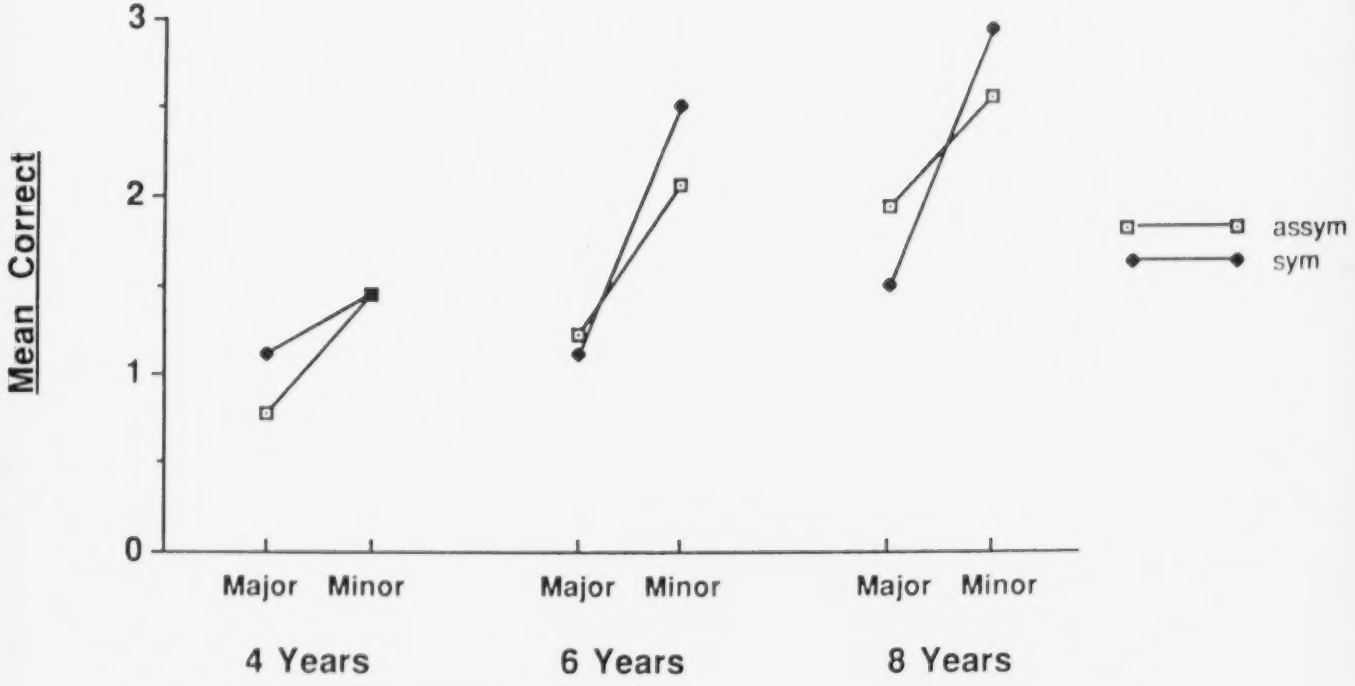


Array B

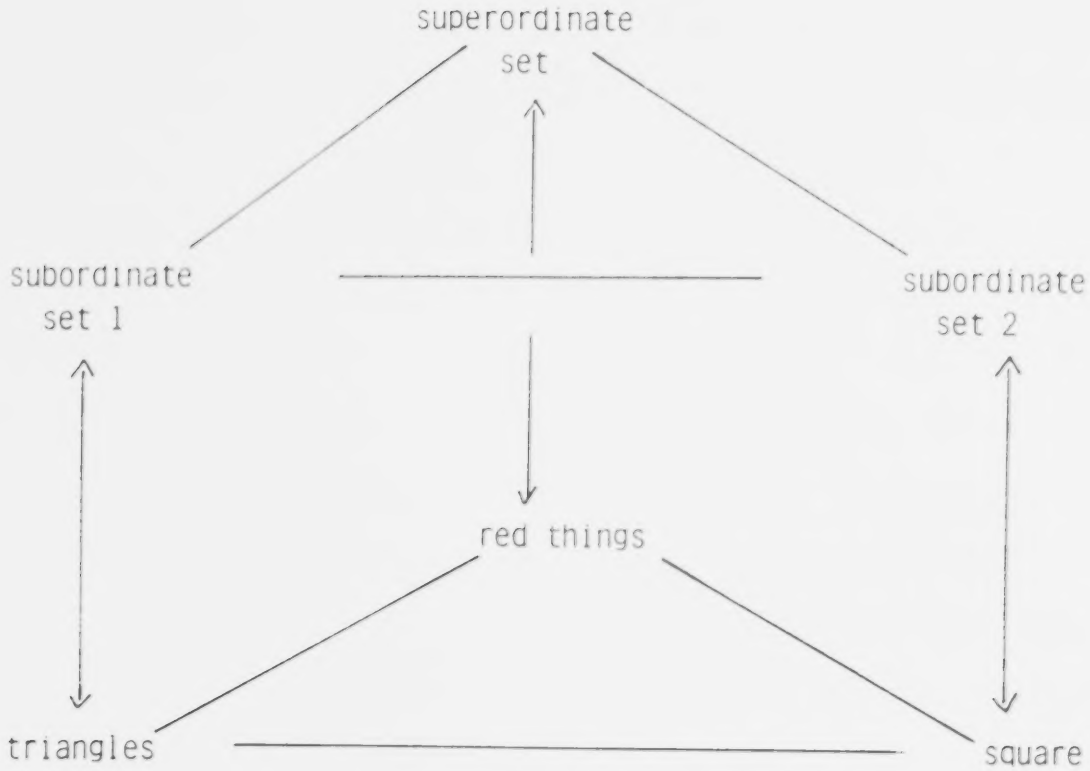
Array C

Questions asked	Arrays used		
asymmetric inclusion: horses vs small horses	A	B	
symmetric inclusion: small horses vs black horses	A		C
same level noninclusion: large horses vs small horses	A		
different level noninclusion: large horses vs black horses	A		
noninclusion: black horses vs white horses		B	C

Fig. 4 Age x Comparison x Subset size interaction



Subset Size x Age



inclusive items

red square, red triangle

disjoint

red square, green triangle

identical

red square, red square

Fig. 6

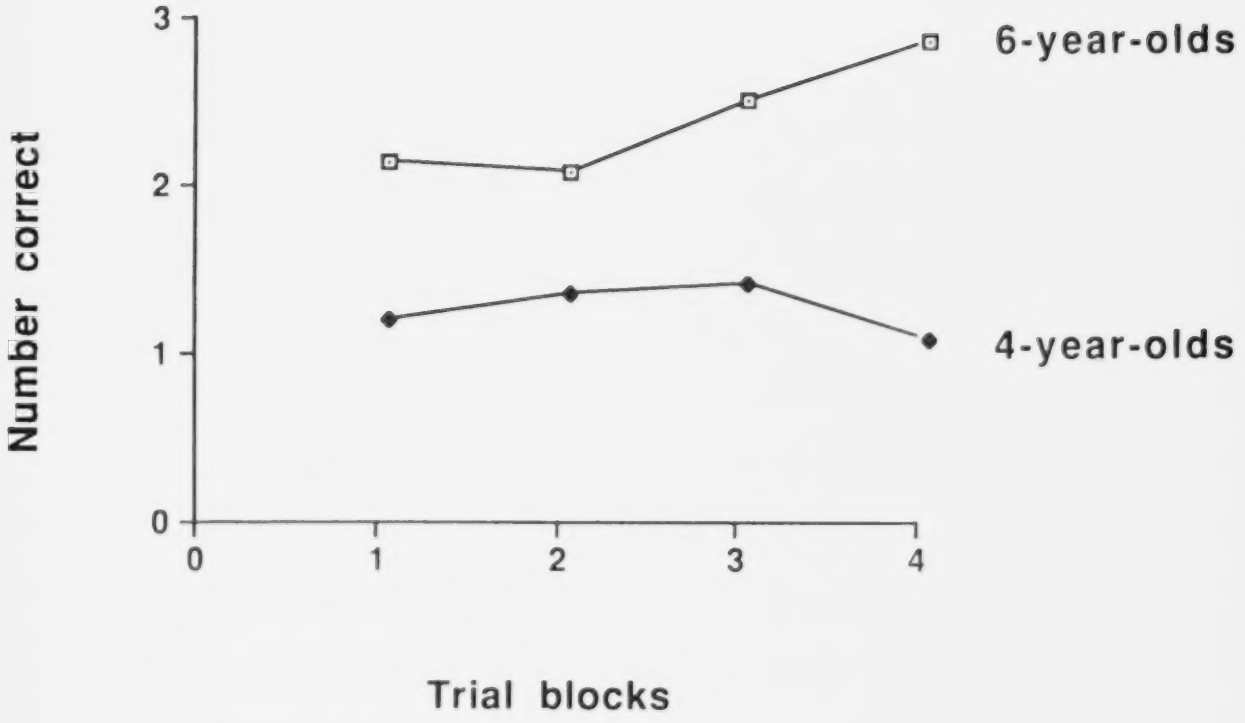

Number correct
3
2
1
0
0
1
2
3
4
6-year-olds
4-year-olds
Trial blocks

Fig. 7

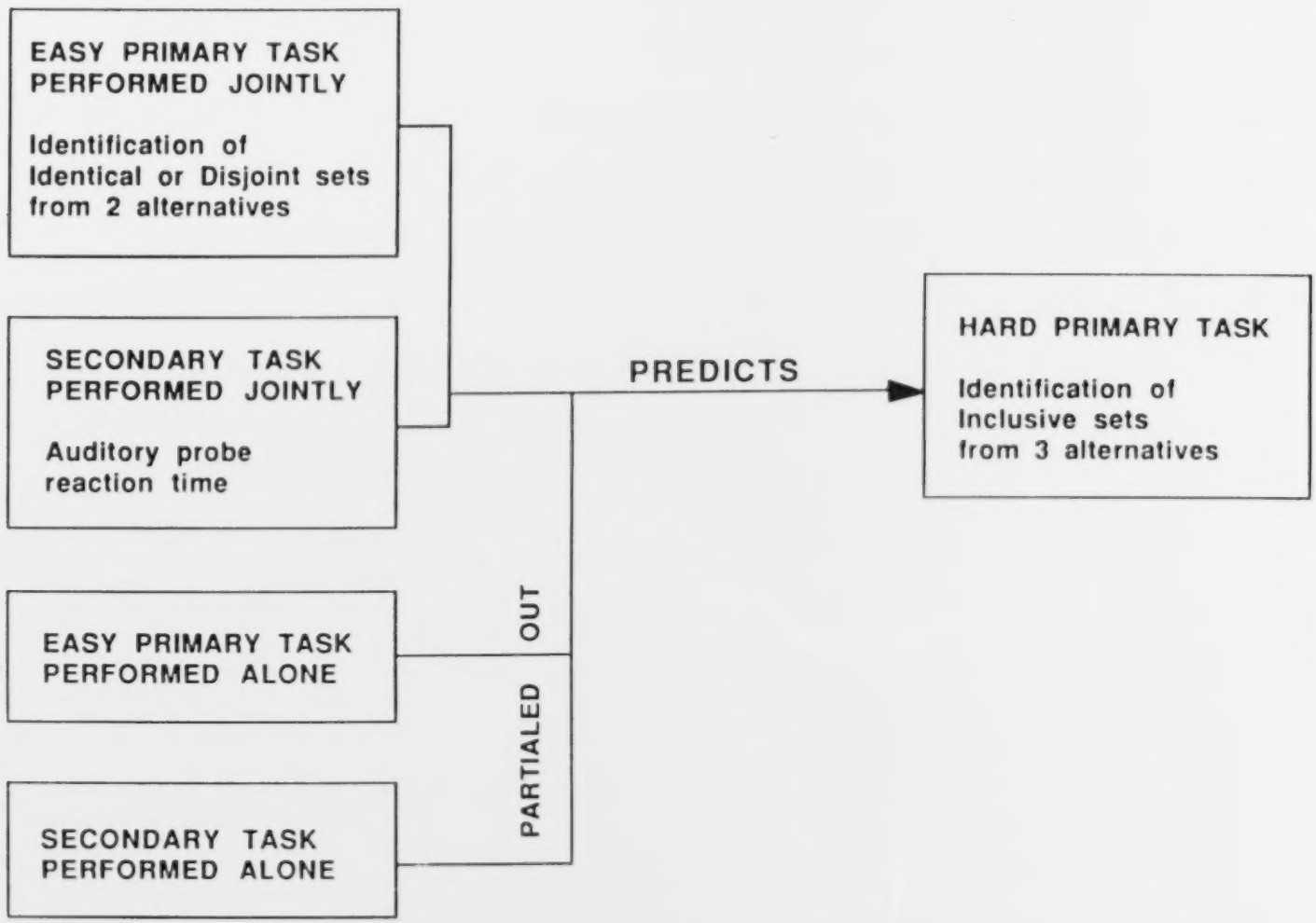

EASY PRIMARY TASK
PERFORMED JOINTLY
Identification of
Identical or Disjoint sets
from 2 alternatives
SECONDARY TASK
PERFORMED JOINTLY
Auditory probe
reaction time
EASY PRIMARY TASK
PERFORMED ALONE
SECONDARY TASK
PERFORMED ALONE
PARTIALED OUT
PREDICTS
HARD PRIMARY TASK
Identification of
Inclusive sets
from 3 alternatives

TABLE 1. MEANS AND STANDARD DEVIATION FOR THE AGE EFFECT, EXPERIMENT 1 (POSSIBLE OF 6).

4 years	6 years	8 years
2.78	4.20	4.90
(1.53)	(1.87)	(1.24)

TABLE 2. MEAN CORRECT RESPONSES, EXPERIMENT I

ASYM INCLUSION	SYM INCL.	NONINCLUSION (SYM.)
3.33	3.57	4.96
(1.82)	(1.68)	(1.41)